

The Role of Soot in Global Climate Change

James Hansen

NASA

Black Carbon Workshop

San Diego, CA

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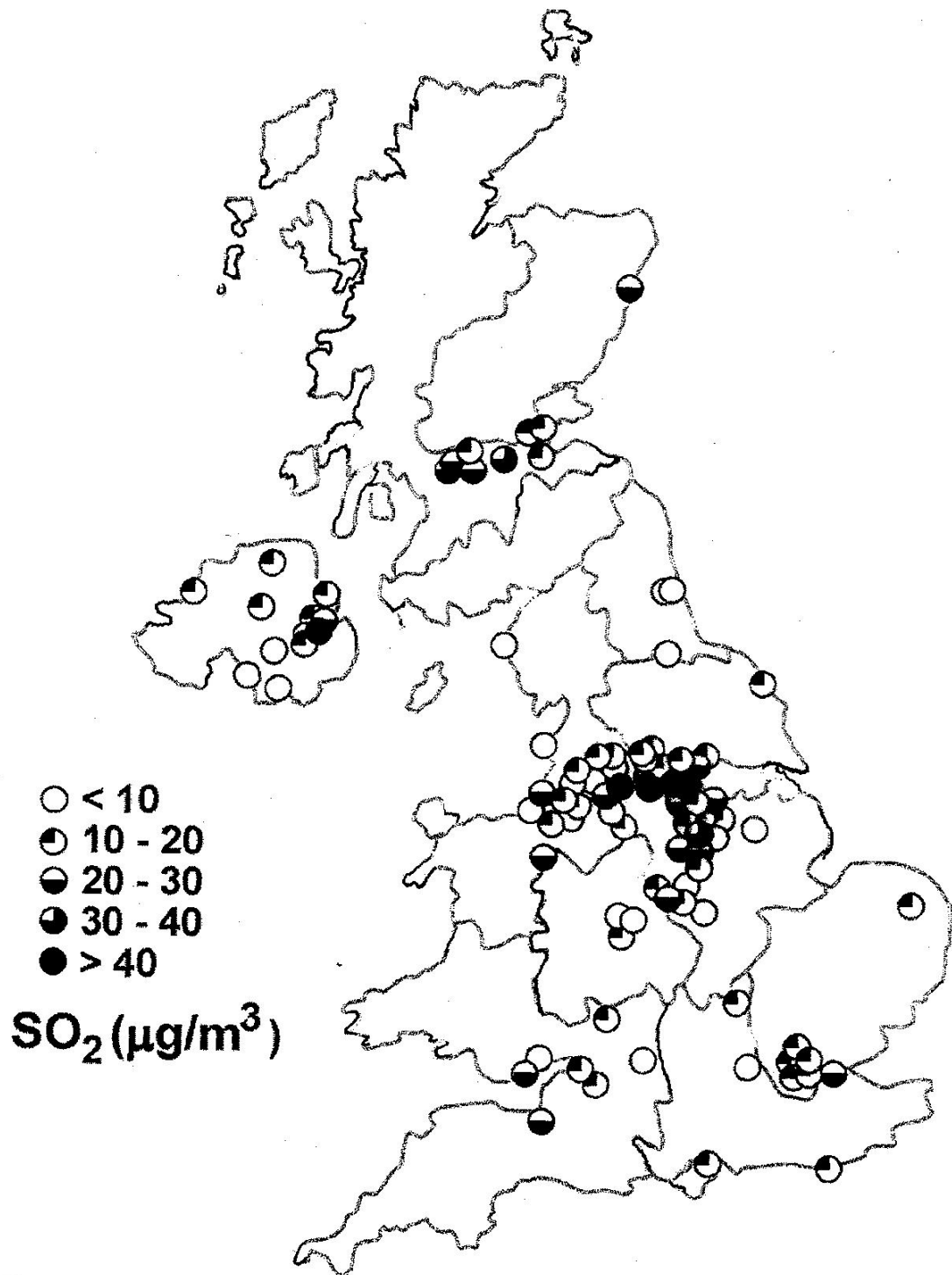


Fig. 1

Soot and Climate

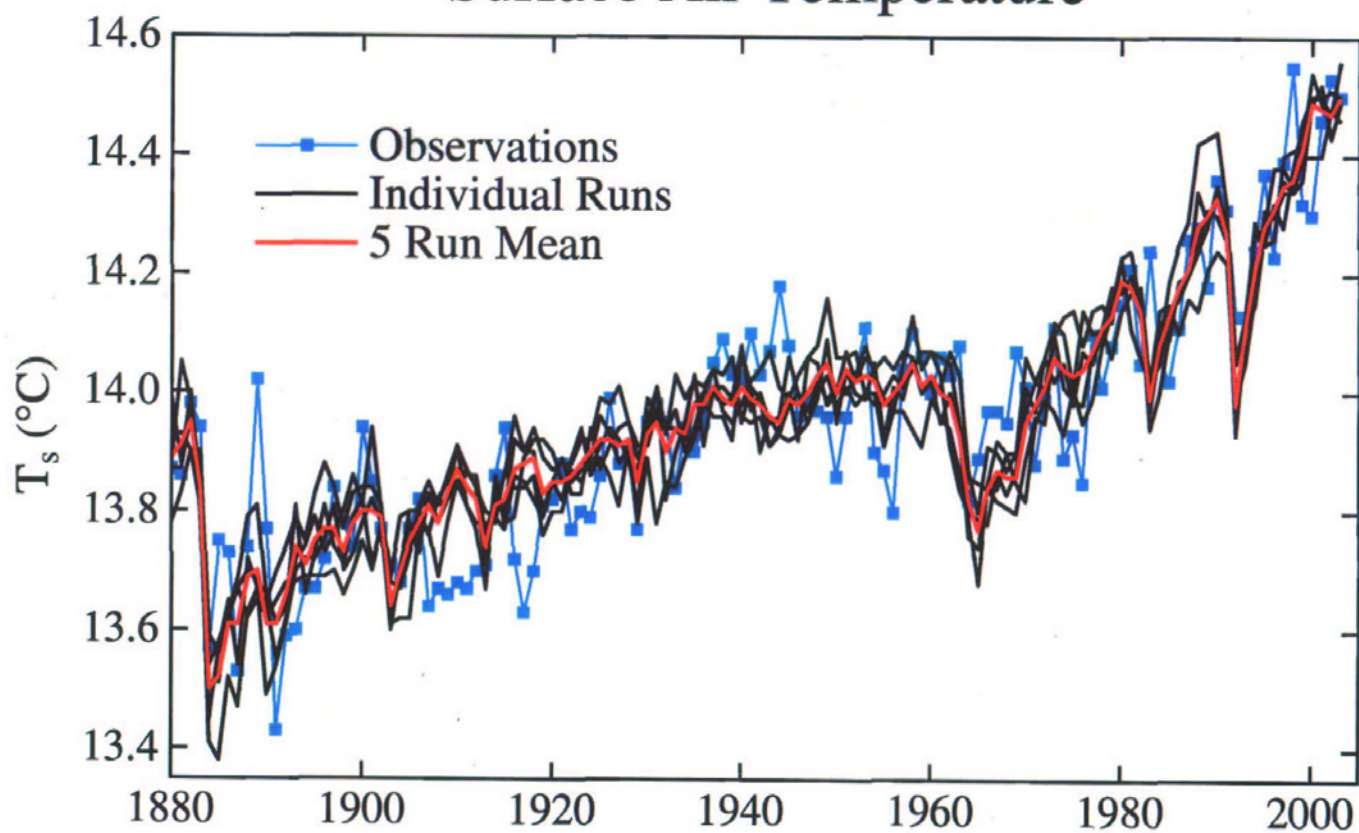
-- a messy discussion

“It’s just good clean soot”

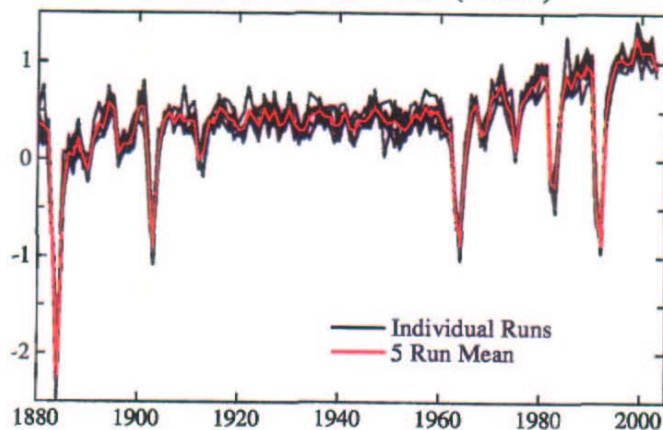
--Dick Van Dyke

Chimney Sweep in Mary Poppins

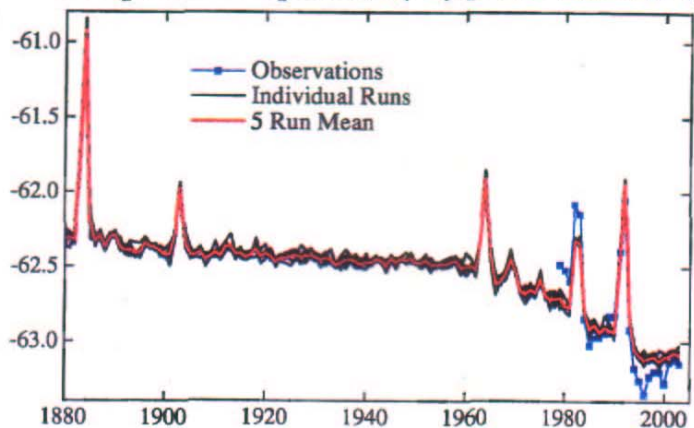
Surface Air Temperature



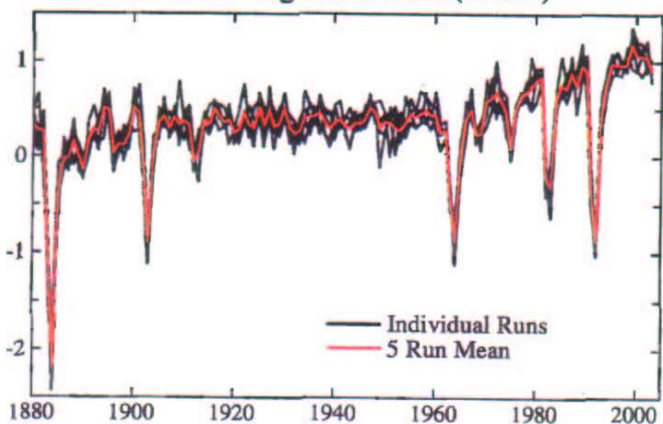
Net Radiation at TOA (W/m^2)



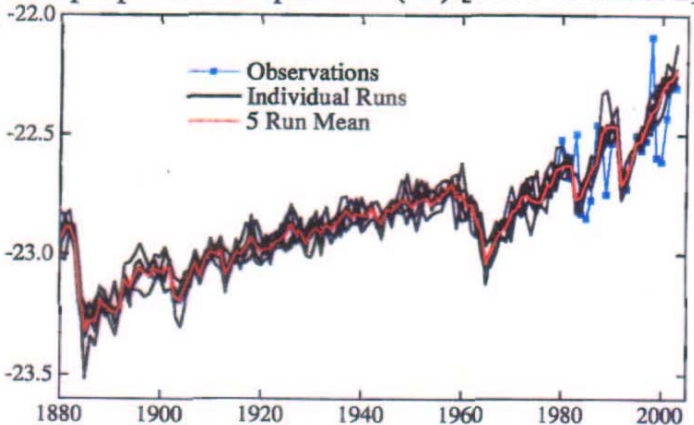
Stratospheric Temperature ($^{\circ}\text{C}$) [MSU Channel 4]



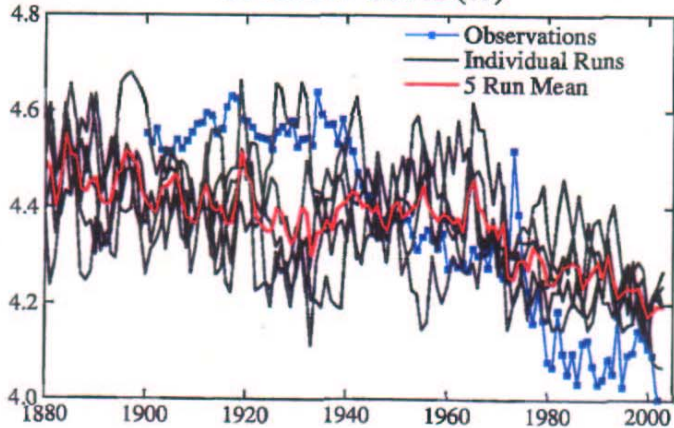
Net Heating at Surface (W/m^2)



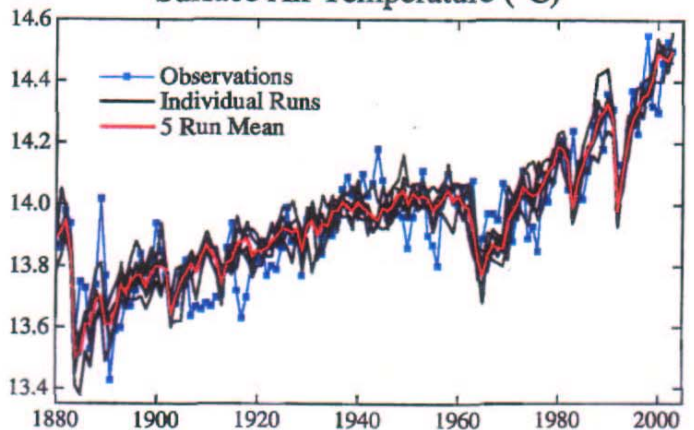
Tropospheric Temperature ($^{\circ}\text{C}$) [MSU Channel 2]



Ocean Ice Cover (%)



Surface Air Temperature ($^{\circ}\text{C}$)



Caveat

“Efficacy” of Forcings

$$1 \text{ W/m}^2 \neq 1 \text{ W m}^2$$

Fossil Fuel Soot*

<u>Forcing (W/m^2)</u>	<u>Efficacy</u>	<u>Effective Forcing (W/m^2)</u>
BCI = +0.53	73%	$+0.39 \pm 0.13$
OCI = -0.13	107%	-0.14 ± 0.07
BCsnow = +0.1	170%	$+0.17 \pm 0.10$
AIEsoot = -0.2	~100%	-0.20 ± 0.10

		$+0.22 \pm 0.21$
		(+15% of 1850-2000 CO₂ forcing)

(BCI = black carbon industrial, OCI = organic carbon industrial, AIE = aerosol indirect effect)

Biomass Burning Soot*

<u>Forcing (W/m^2)</u>	<u>Efficacy</u>	<u>Effective Forcing (W/m^2)</u>
BCB = +0.20	55%	$+0.11 \pm 0.05$
OCB = -0.12	93%	-0.11 ± 0.05
BCsnow = +0.05	170%	$+0.08 \pm 0.05$
AIEsoot = -0.3	~100%	-0.30 ± 0.15

		-0.22 ± 0.17
		(-15% of 1850-2000 CO₂ forcing)

***These are preliminary estimates that may be modified prior to publication.**

Climate researchers are finally homing in on just how bad greenhouse warming could get—and it seems increasingly unlikely that we will escape with a mild warming

Three Degrees of Consensus

PARIS—Decades of climate studies have made some progress. Researchers have convinced themselves that the world has indeed warmed by 0.6°C during the past century. And they have concluded that human activities—mostly burning fossil fuels to produce the greenhouse gas carbon dioxide (CO₂)—have caused most of that warming. But how warm could it get? How bad is the greenhouse threat anyway?

For 25 years, official assessments of climate science have been consistently vague on future warming. In report after report, estimates of climate sensitivity, or how much a given increase in atmospheric CO₂ will warm the world, fall into the same subjective range. At the low end, doubling CO₂—the traditional benchmark—might eventually warm the world by a modest 1.5°C, or even less. At the other extreme, temperatures might soar by a scorching 4.5°, or more warming might be possible, given all the uncertainties.

At an international workshop* here late last month on climate sensitivity, climatic wishy-washiness seemed to be on the wane. “We’ve gone from hand waving to real understanding,” said climate researcher Alan Robock of Rutgers University in New Brunswick, New Jersey. Increasingly sophisticated climate models seem to be converging on a most probable sensitivity. By running a model dozens of times under varying conditions, scientists are beginning to pin down statistically the true uncertainty of the models’ climate sensitivity. And studies of natural climate changes from the last century to the last ice age are also yielding climate sensitivities.

Although the next international assessment is not due out until 2007, workshop participants are already reaching a growing con-

sensus for a moderately strong climate sensitivity. “Almost all the evidence points to 3°C” as the most likely amount of warming for a doubling of CO₂, said Robock. That kind of sensitivity could make for a dangerous warming by century’s end, when CO₂ may have doubled. At the same time, most attendees doubted that climate’s sensitivity to doubled CO₂ could be much

for Climate Studies (GISS) in New York City.

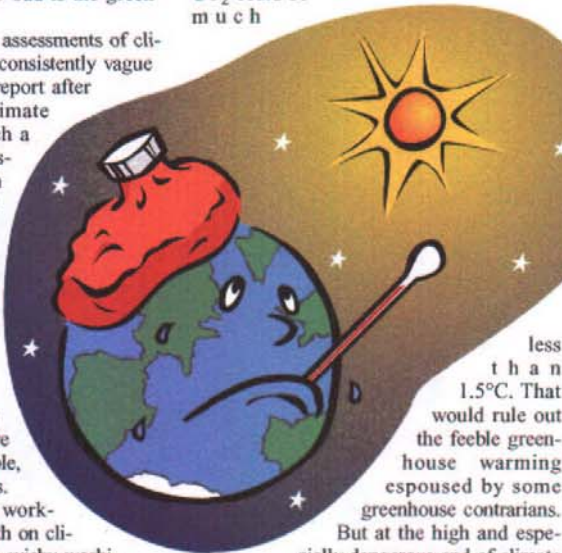
On the first day of deliberations, Manabe told the committee that his model warmed 2°C when CO₂ was doubled. The next day Hansen said his model had recently gotten 4°C for a doubling. According to Manabe, Charney chose 0.5°C as a not-unreasonable margin of error, subtracted it from Manabe’s number, and added it to Hansen’s. Thus was born the 1.5°C-to-4.5°C range of likely climate sensitivity that has appeared in every greenhouse assessment since, including the three by the Intergovernmental Panel on Climate Change (IPCC). More than one researcher at the workshop called Charney’s now-enshrined range and its attached best estimate of 3°C so much hand waving.

Model convergence, finally?

By the time of the IPCC’s second assessment report in 1995, the number of climate models available had increased to 13. After 15 years of model development, their sensitivities still spread pretty much across Charney’s 1.5°C-to-4.5°C range. By IPCC’s third and most recent assessment report in 2001, the model-defined range still hadn’t budged.

Now model sensitivities may be beginning to converge. “The range of these models, at least, appears to be narrowed,” said climate modeler Gerald Meehl of the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, after polling eight of the 14 models expected to be included in the IPCC’s next assessment. The sensitivities of the 14 models in the previous assessment ranged from 2.0°C to 5.1°C, but the span of the eight currently available models is only 2.6°C to 4.0°C, Meehl found.

If this limited sampling really has detected a narrowing range, modelers believe there’s a good reason for it: More-powerful computers and a better understanding of atmospheric processes are making their models more realistic. For example, researchers at the Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton, New Jersey, recently adopted a better way of calculating the thickness of the bottommost atmospheric layer—the boundary layer—where clouds form that are crucial to the planet’s heat bal-



But at the high and especially dangerous end of climate sensitivity, confidence faltered; an upper limit to possible climate sensitivity remains highly uncertain.

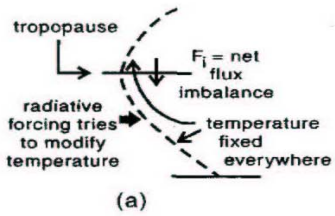
Hand-waving climate models

As climate modeler Syukuro Manabe of Princeton University tells it, formal assessment of climate sensitivity got off to a shaky start. In the summer of 1979, the late Jule Charney convened a committee of fellow meteorological luminaries on Cape Cod to prepare a report for the National Academy of Sciences on the possible effects of increased amounts of atmospheric CO₂ on climate. None of the committee members actually did greenhouse modeling themselves, so Charney called in the only two American researchers modeling greenhouse warming, Manabe and James Hansen of NASA’s Goddard Institute

* Workshop on Climate Sensitivity of the Intergovernmental Panel on Climate Change Working Group I, 26–29 July 2004, Paris.

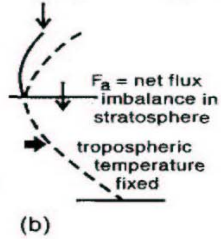
We obtain a third measure of the climate forcing, $F_s = F_o + \delta T_o / \lambda$, by running the global climate model with SST and SI fixed. F_o and δT_o are, respectively, the flux change at the top of (and throughout) the atmosphere and the global surface air temperature change after the forcing is introduced with SST and SI fixed. λ is the model's equilibrium climate sensitivity ($^{\circ}\text{C}$ per W/m^2 , evaluated from doubled CO_2).

Instantaneous Forcing, F_i

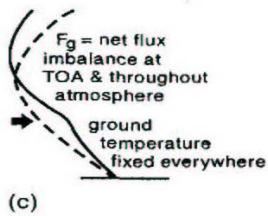


Adjusted Forcing, F_a

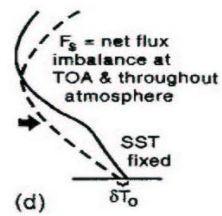
stratospheric T adjusts



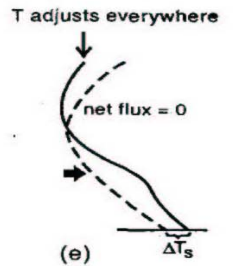
Fixed T_g Forcing, F_g

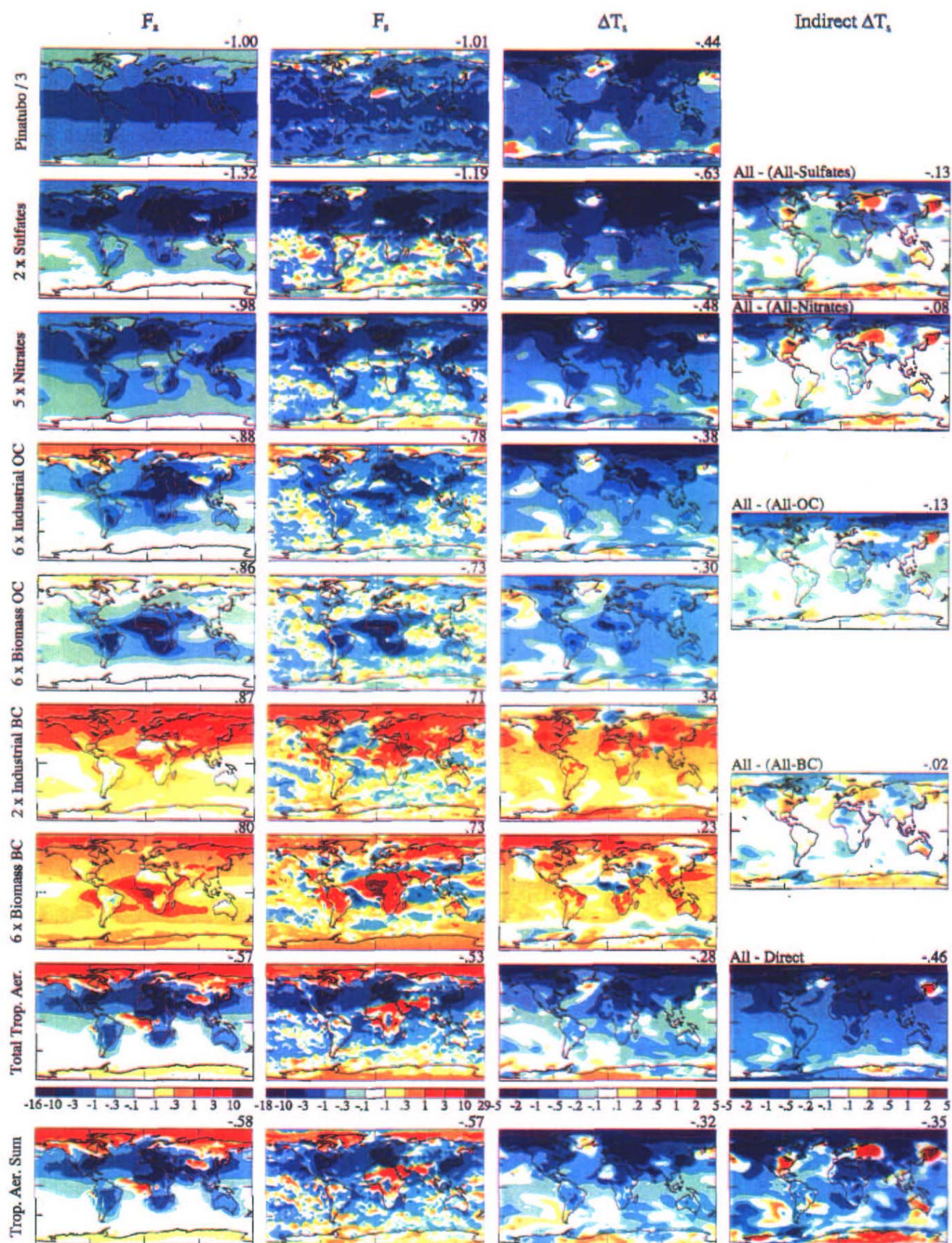


Fixed SST Forcing, F_s

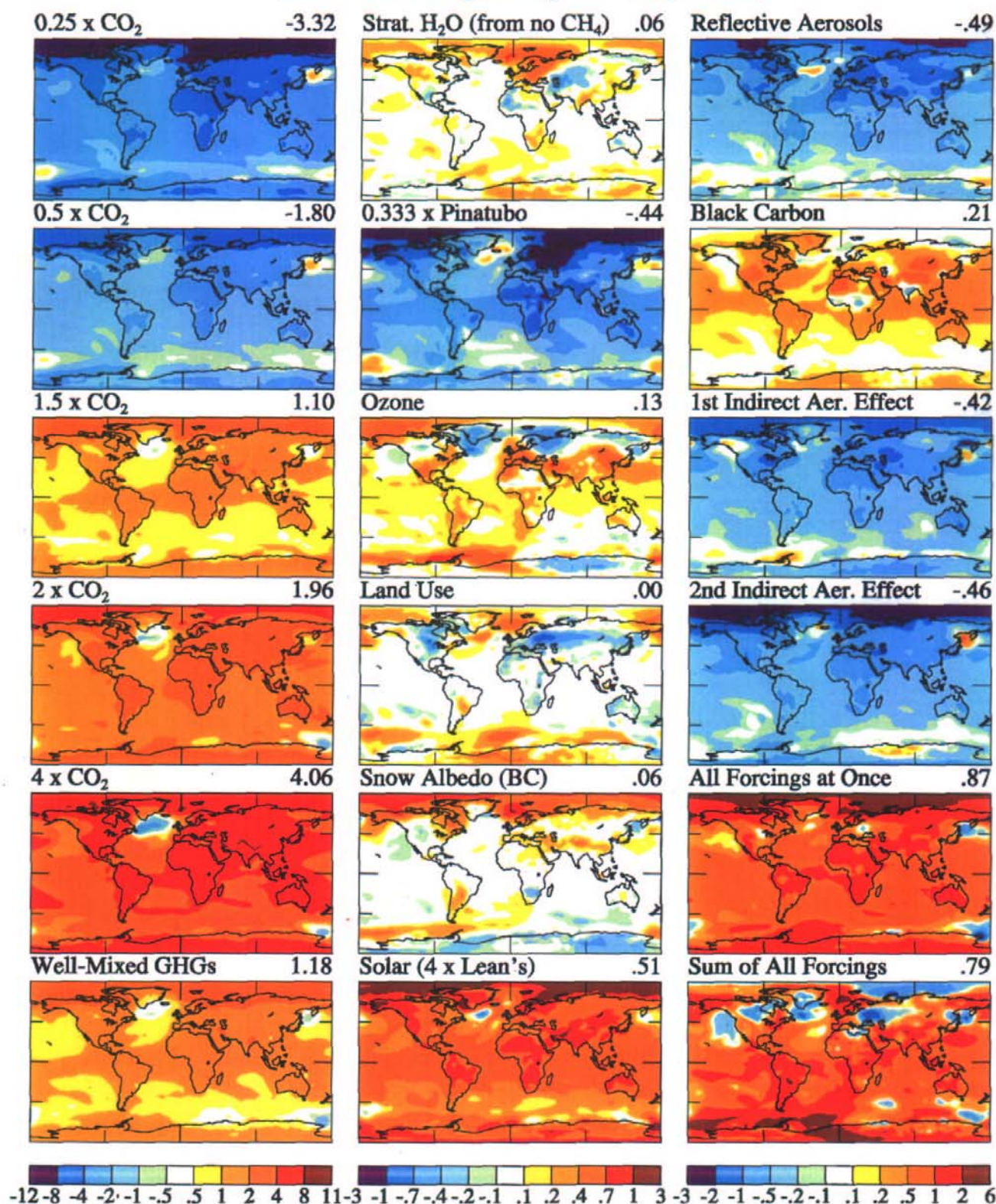


All Feedback Response, ΔT_s





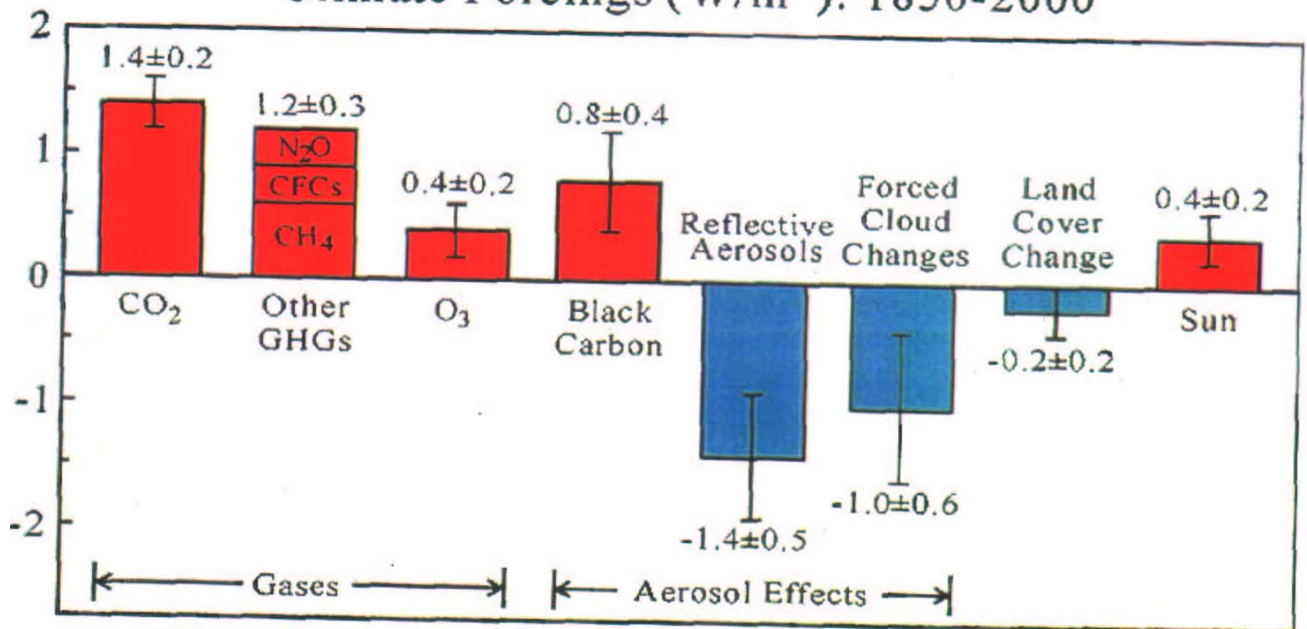
Surface Temperature Change (°C) (1880-2000 Change Except Where Specified)



Climate Forcing Agents in the Industrial Era

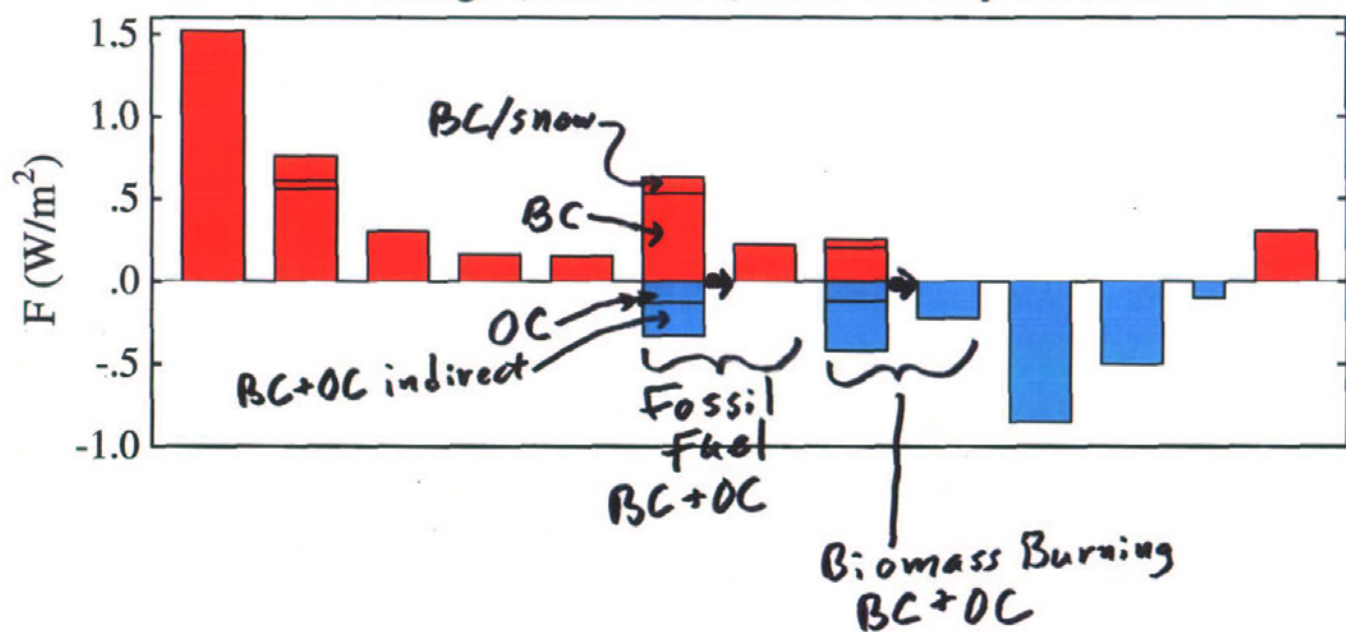
- CO₂ is the largest forcing, but others are significant.
- Air pollution (BC, O₃, CH₄) causes a large forcing.
- Aerosol effects (direct and on clouds) most uncertain.

Climate Forcings (W/m²): 1850-2000

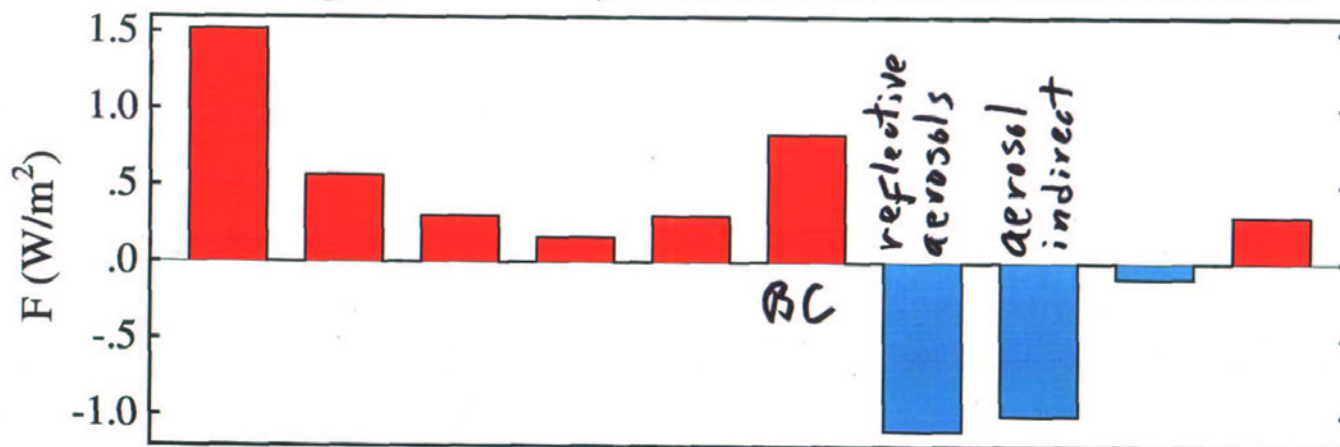


Climate forcing agents in the industrial era. Error bars are partly subjective 1 σ (standard deviation) uncertainties.

Forcings (1850-2000) Portioned by Sources

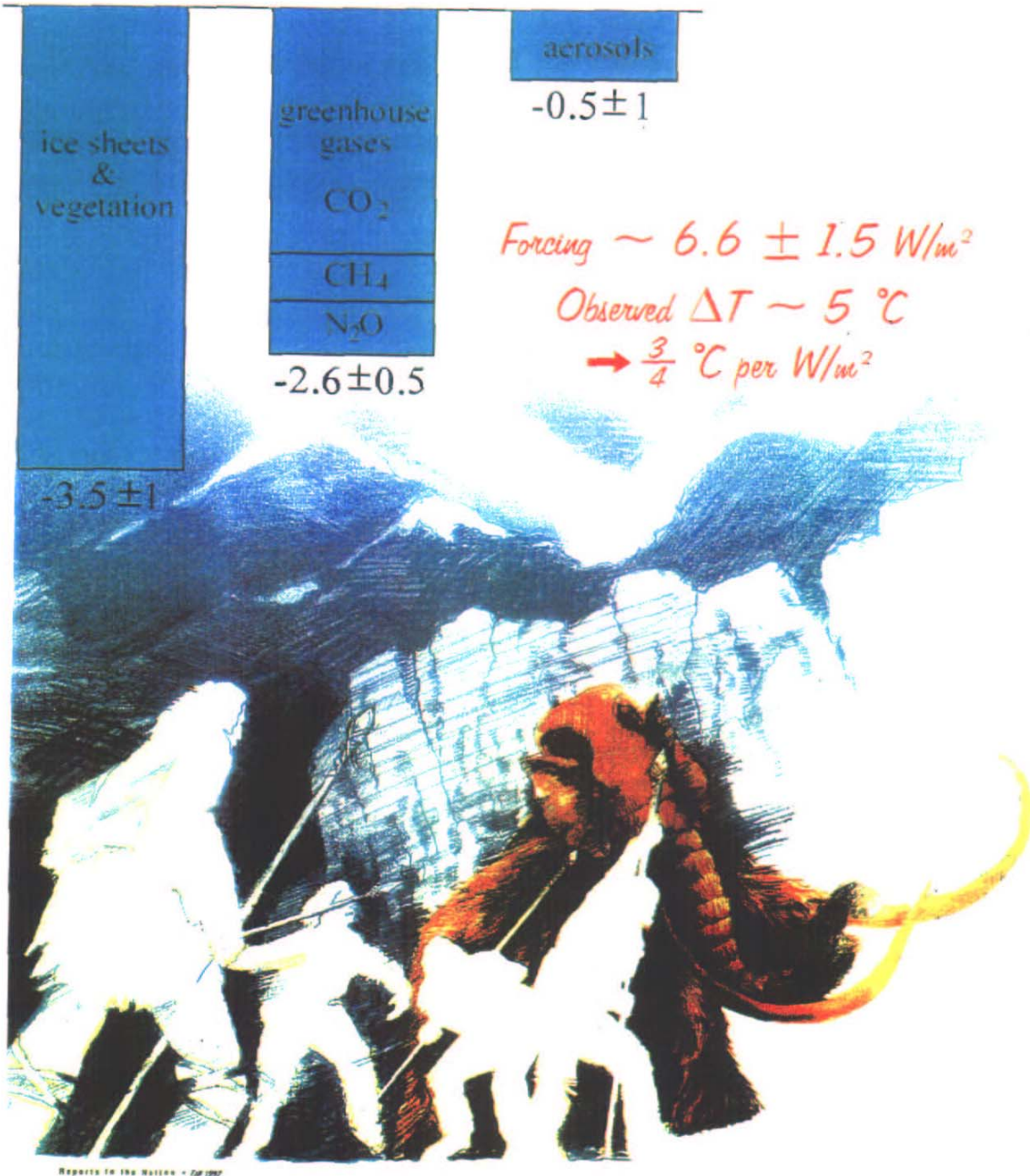


Forcings (1850-2000) in Simulation #1 of GISS Model III



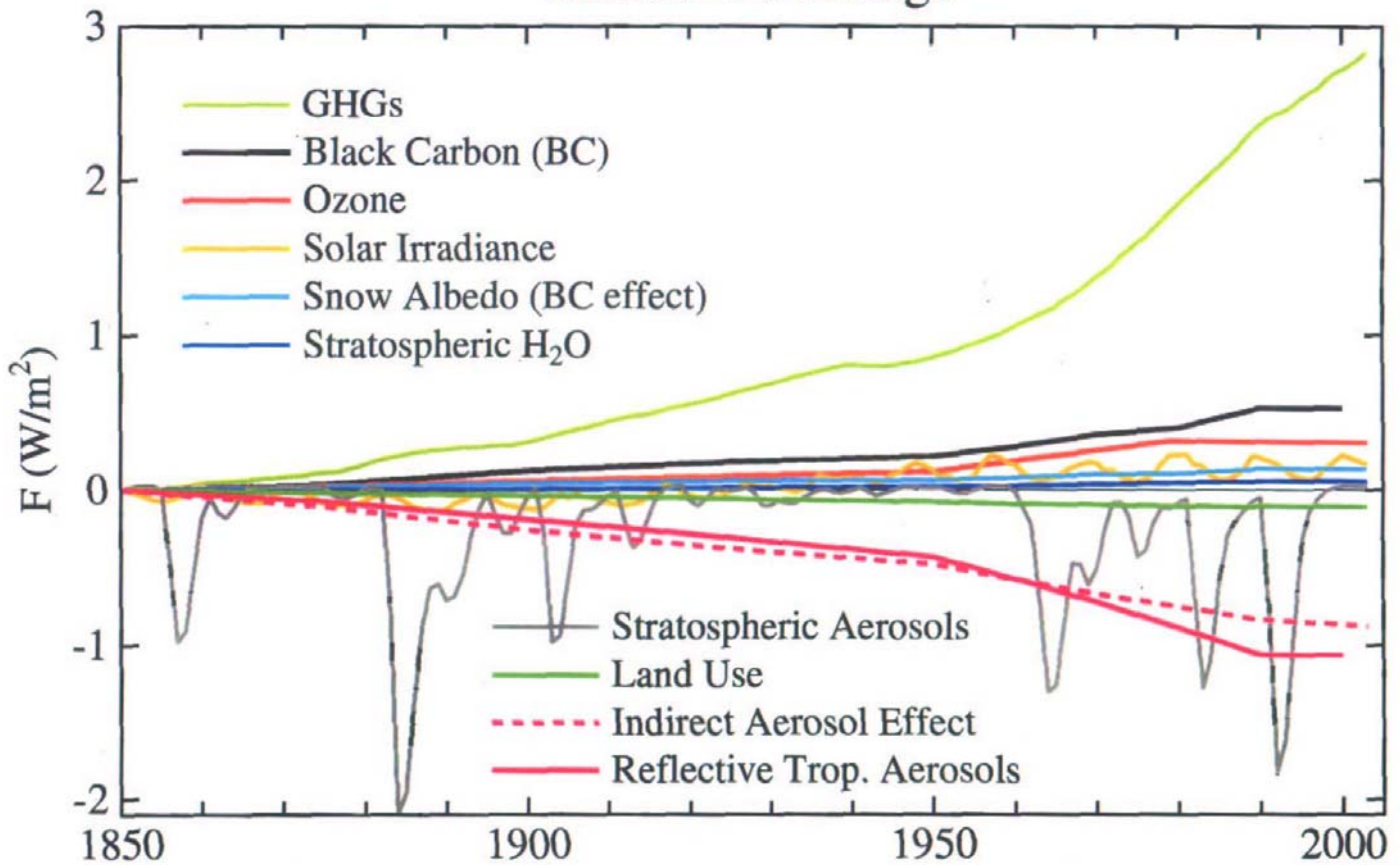
The Last Ice Age

Ice Age Climate Forcings (W/m^2)



The last ice age, 20,000 years ago, was maintained by a global climate forcing of about $6\frac{1}{2} \text{ W/m}^2$.

Radiative Forcings





Faustian Aerosol Bargain